Argonne NATIONAL LABORATORY

Energy and Petroleum Consumption Attributes of Plug-in Hybrids

Presented at:

CARB PHEV Discussion Meeting

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Many Questions and Technology Options Were Not Previously Examined

- **Items not addressed in 2001 studies by EPRI and Argonne**
  - **Li-ion batteries**
  - **Varying electric operations capabilities – top speed, acceleration rate**
  - **Effects of highly variable, often wide SOC swings on battery power/life**
  - **Multiple HEV powertrain configurations**
  - **In-use vs. certification cycle fuel economy**
  - **Charge depletion w/o EV only operation (“blended mode”)**
  - **Incremental cost/benefit evaluations**
  - **Towing requirement effects**
  - **Isolation of HEV vs. PHEV incremental benefit/cost**
  - **Urban vs. non-urban & morning vs. other emissions**
  - **Detailed comparison of trip characteristics to potential PHEV capabilities**

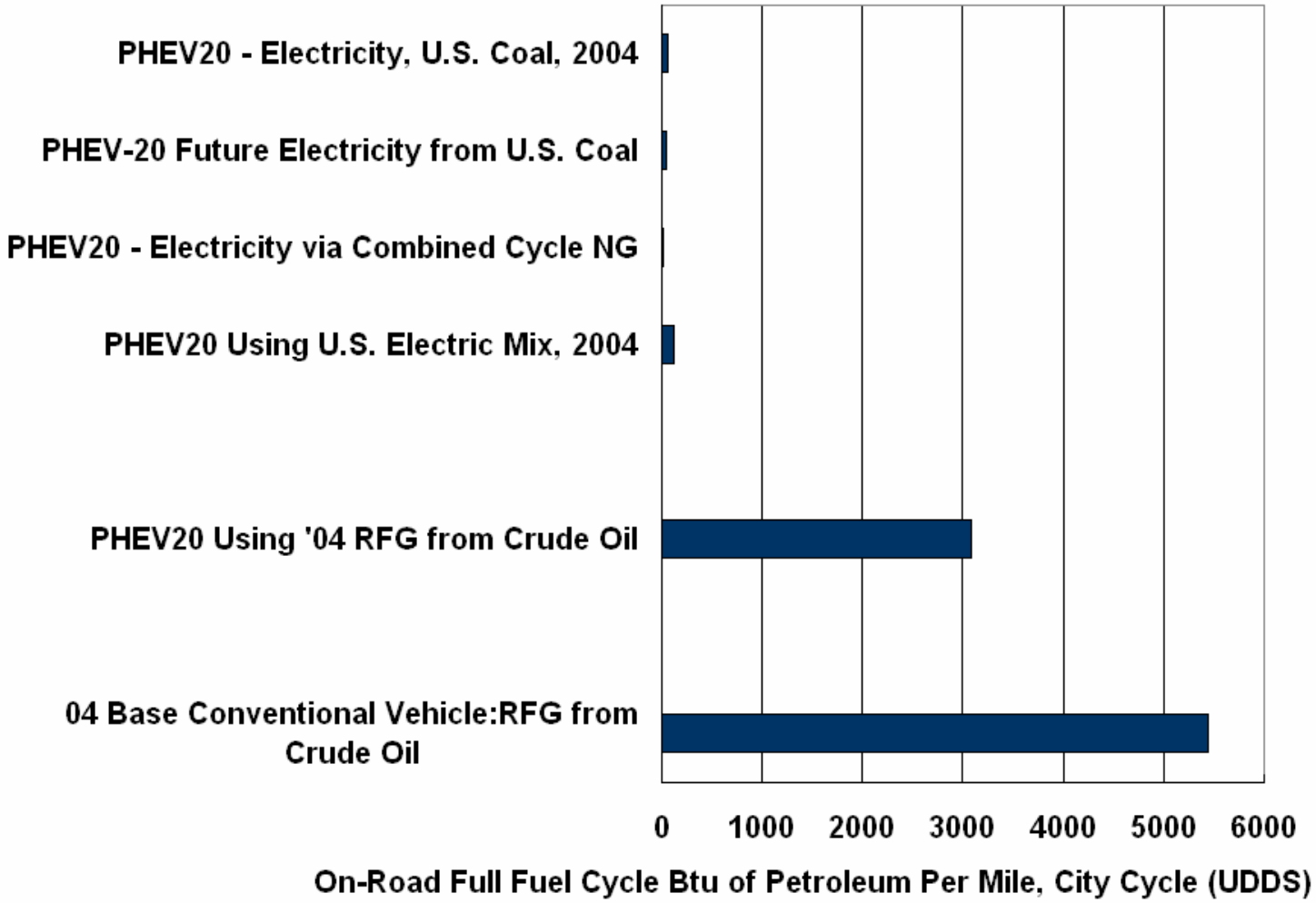
Topics

- Why the expanding interest in PHEVs?
- Would massive success with PHEVs stress power generation?
- Would massive success stress the grid?
- What new sources of power would be favored for expansion?
- How will pattern of driving interact with desired PHEV capability?
- How would successful R&D, achieving cost reduction, affect patterns of PHEV preference?
- Illustrations of some of the technical problems to address

Why more interest in plug-in hybrids with new EPACT legislation authorizing new government/industry programs?

- **Oil savings** (heightened interest due to oil price increases)
- Focus of 2001 studies: CA desire for zero tailpipe emissions
- Greenhouse gas reductions (cumulative climate change science)
- Electric utility efficiency (load leveling)
- Emergency services (hurricanes, power failures, spot gasoline shortages)
- Improvements in li-ion battery technology
  - (li-ion eclipses NiMH in consumer electronics)

Oil Savings: Each PHEV (Full HEV) Sharply Reduces Oil Use Even If No Electricity is Used, Far More if Electricity is Used



Oil Use, Electric Generation Expansion, Change in Power Plant Mix and Greenhouse Gases With PHEVs in Future Decades:

3 National Lab PHEV Scenario Analyses

(Others coming from EPRI, from EPA, more from National Labs)

Studies from National Labs

Possible long-and short-term incremental impacts of PHEVs

Short-term: Power plant dispatch choice

- Coal is presently cheapest
- Combined cycle natural gas is available, clean, but more costly

Long-term:

- Acceleration of efficient, clean advanced base load plants likely
- Wind appears to match very well with PHEVs

Oil use will certainly decline

GHGs can decline in the short term, probably will significantly decline in the long term.

PNNL Electric Infrastructure Capability Study Early Findings Show >> National Reserve Capacity to Serve PHEVs Than Needed, But …

Preliminary conclusions:

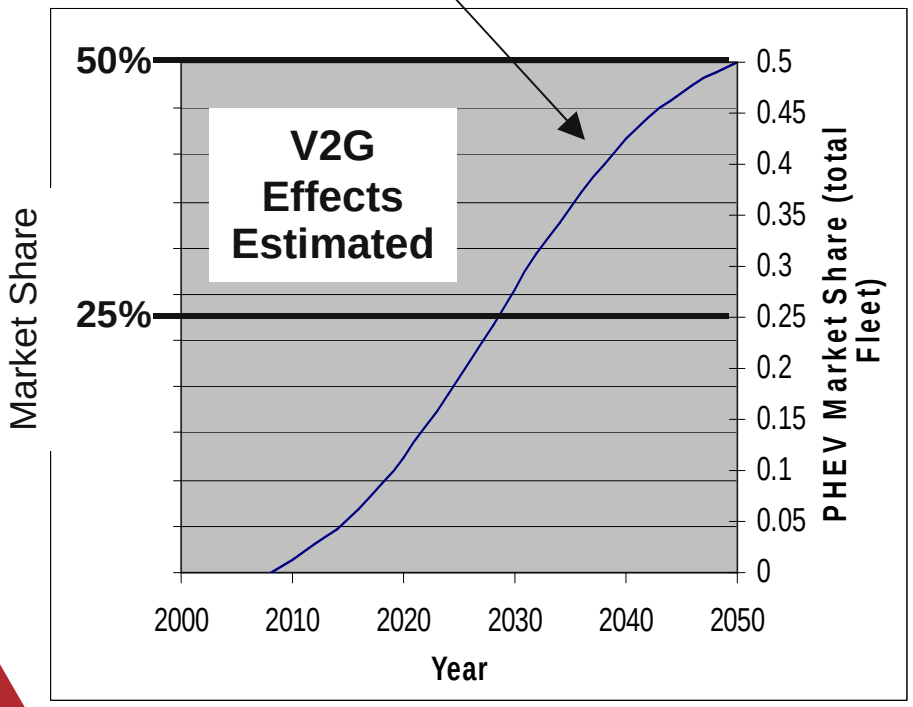
- Idle grid capacity (generation, T&D) is adequate to supply ~50% - 65% (or more) of energy for U.S. cars and light trucks at hybrid performance levels
- There are significant regional differences based on varying reserve margins across regions
- Todays' CO_2 impacts approximately neutral for today's baseload and intermediate plants (10% above or below current emissions depending on region)
- Significant issues for coordinating vehicle charging with grid peak loads, reliability needs, and market and other signals

What Could The Effect on Oil Use, Electric Generation, and Carbon Emissions Be if Massive Success of PHEVs Were Achieved?

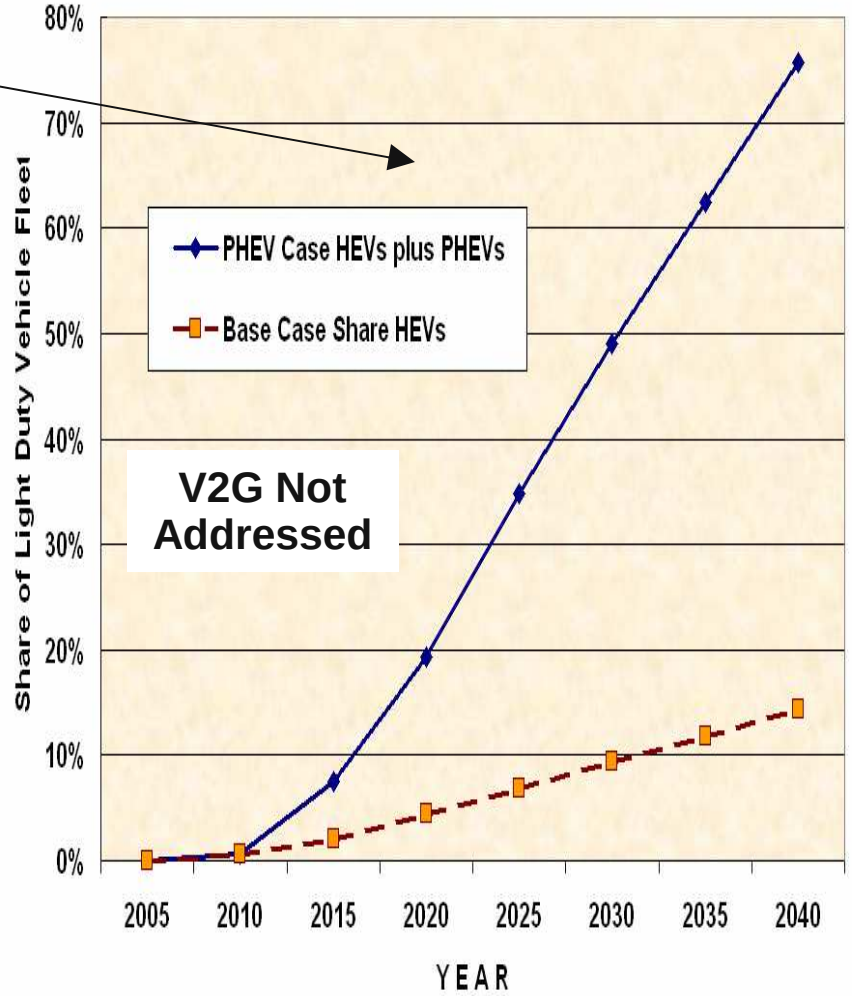
"What If" scenarios

AMIGA Scenario by Argonne

WinDS Scenario by NREL



Courtesy of W. Short, NREL



Courtesy of D. Hanson, Argonne

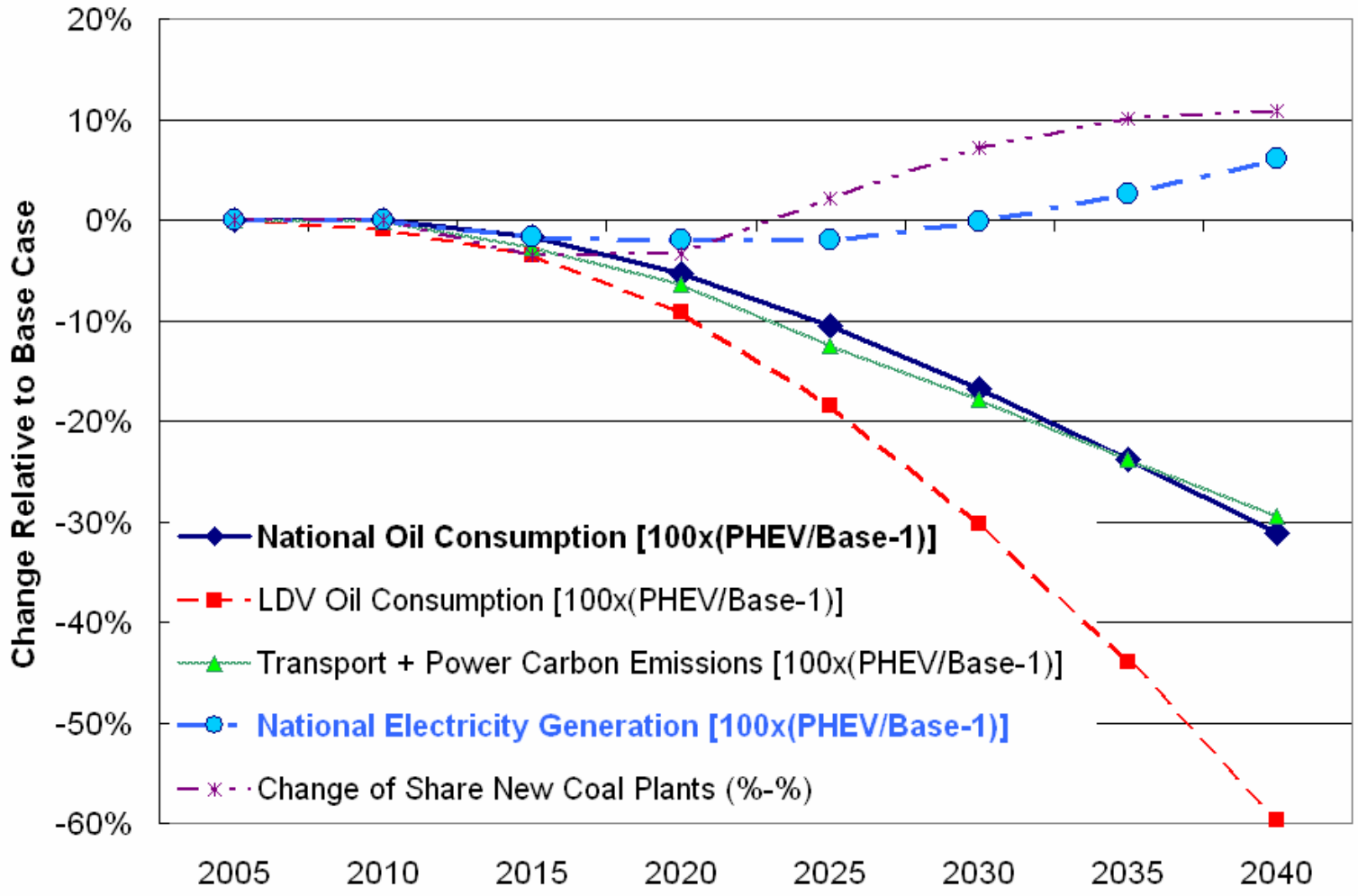
Massive Success Requires a Few Percent Increase in Total Generation, Leads to Significant Use of Wind Power

Summary of 2050 WinDS/PHEV Results – PHEV Cases Compared to Base Case

2050 Projected Values	Base Case (no PHEVs)	PHEV-20 Case	PHEV-60 Case
Gasoline use (Billions of Gallons)	368	255 (31% decrease)	212 (43% decrease)
Wind Generation (TWh/year)	757	853 (13% increase)	1554 (105% increase)
Total Load (TWh/year)	9392	9808 (4.4% increase due to PHEV load)	10082 (7.3% increase due to PHEV load)
Increase of Wind Electricity vs. Base Case	-	0.6%	7.5%
Total Installed Generation Capacity (GW)	2161	2092	1972
Generation from Coal (TWh/year)	8272	8597 (3.9% increase)	8169 (1% decrease)
Electric and Light Duty Transport Sector CO2 (Million Tons CO2/year)	10956	9910 (9.5% decrease)	9346 (14.7% decrease)

Courtesy of W. Short, NREL

With A Higher PHEV Penetration Scenario Than in WinDS, AMIGA Obtains Higher Oil Savings (also by Including Coal-to-Liquids for Co-Production of Diesel Fuel and Electricity)



What Should be Assumed to be the Long Term Incremental Source of PHEV Electricity?

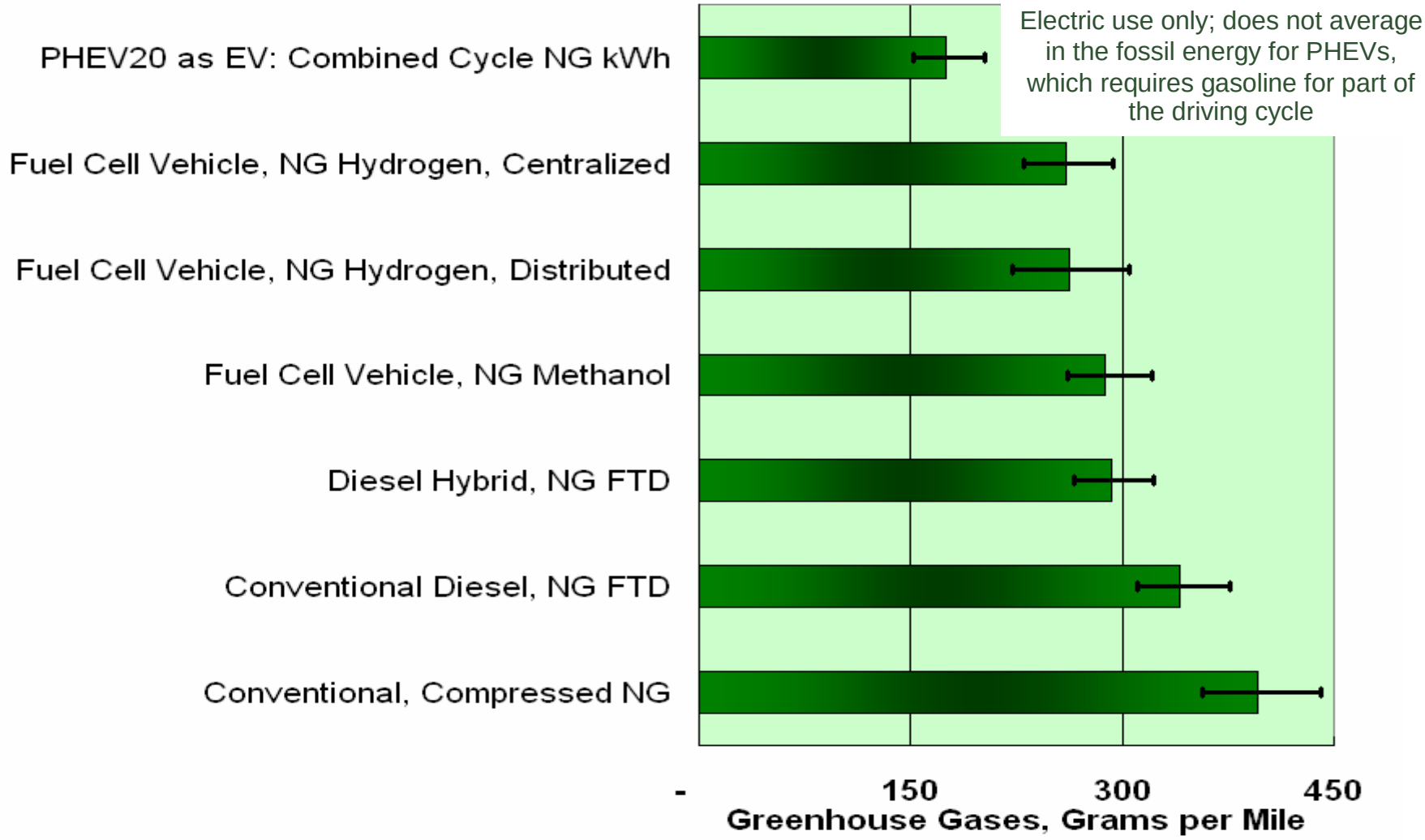
PREDICTED CONTRACTING & STABLE SHARES IF PHEVs SUCCEED

- **Coal: AMIGA and WinDS PHEV60 cases predict reduced coal use**
- **Nuclear: WinDS decline, AMIGA steady production share**
- **Oil and Gas: WinDS uses AEO declines for "oil-gas-steam" power plants, and assumed a high gas price, shrinking other natural gas**

PREDICTED INCREASING SHARES

- **Wind**
  - **Both AMIGA and WinDS predict more expansion of wind than natural gas or "other" (renewable) power generation**
- **Other (hydro, biomass, geothermal, waste to electricity, solar)**
  - **AMIGA predicts an increase**
- **Natural Gas**
  - **AMIGA predicts some expansion of natural gas**

If Natural Gas is Used to Create Vehicle Fuels, NGCC-derived Electricity for PHEVs Can Result in Less Depletion of Natural Gas, Less GHGs/Mile

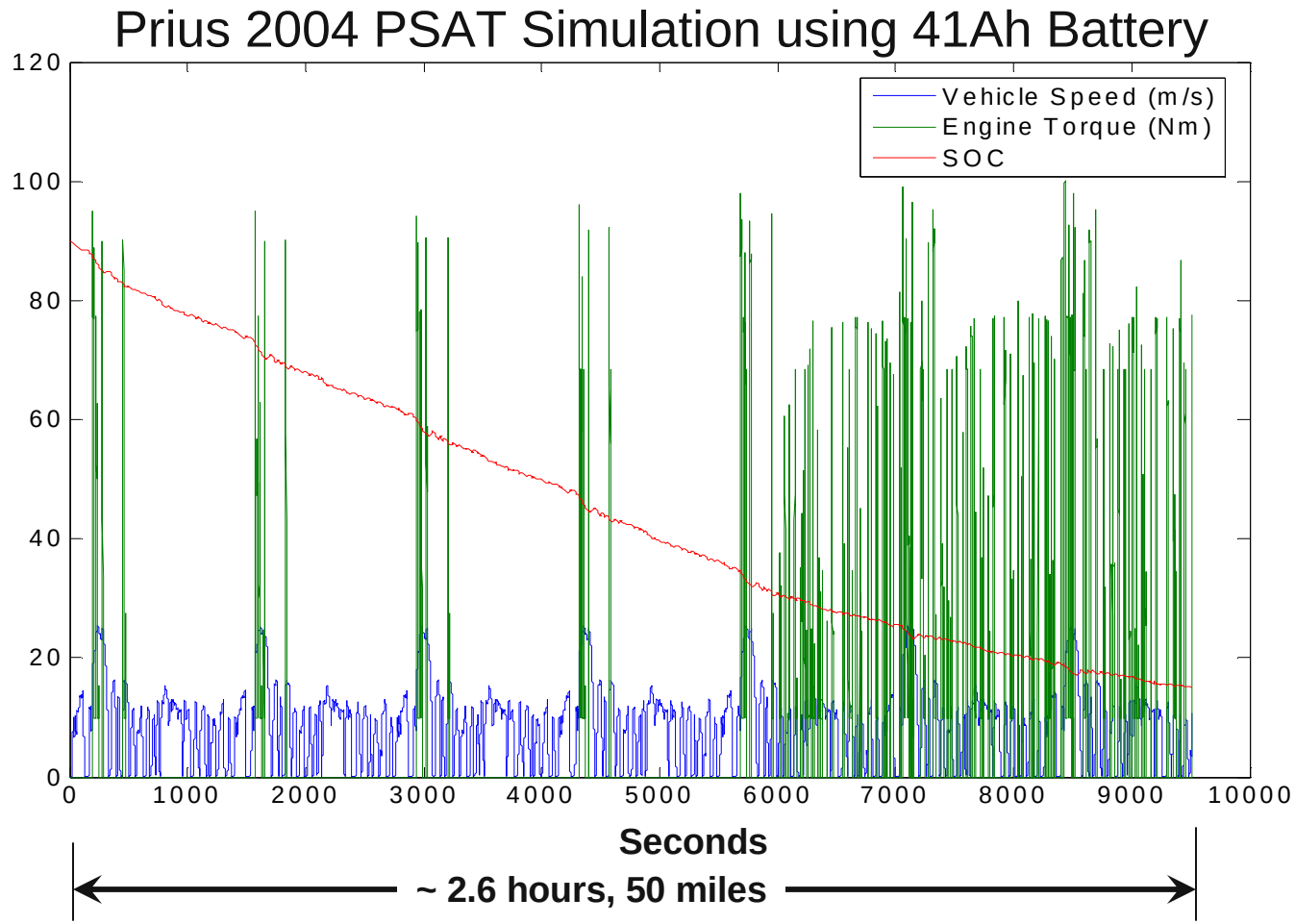


Courtesy of Y. Wu and M. Wang, Argonne. Results are early preliminary.

Question: Should PHEV design strategy be to satisfy a national market with a focus on oil use and perhaps GHGs, allowing “blended” charge depletion control strategies?

Or (and) should there be a design strategy be for key urban markets with poor air quality, requiring on ZEV charge depletion?

Simulation of a Hypothetical Prius PHEV Conversion Implies Intermittent Engine Starts and Relatively Slow Battery Depletion on UDDS



Implication: a "blended" control strategy takes more miles to use stored grid electricity.

Source: PSAT simulations courtesy of A. Rousseau, Argonne

Average National Miles Per Day > 30 Miles, But Typically Composed of Several Short Trips

- Instrumented vehicle results
  - Baltimore 4.0-5.9 mi.- average of 4.9
  - Spokane 3.6 mi.
  - Atlanta 6.0 mi.
- EPA MOVES 2004 assumptions
  - Passenger cars: 4.4 mi., 7 starts/ average day
  - Light trucks < 6000 lb: 4.8 mi., 7 starts/ average day
  - Light trucks > 6000 lb: 4.6 mi., 7 starts/ average day

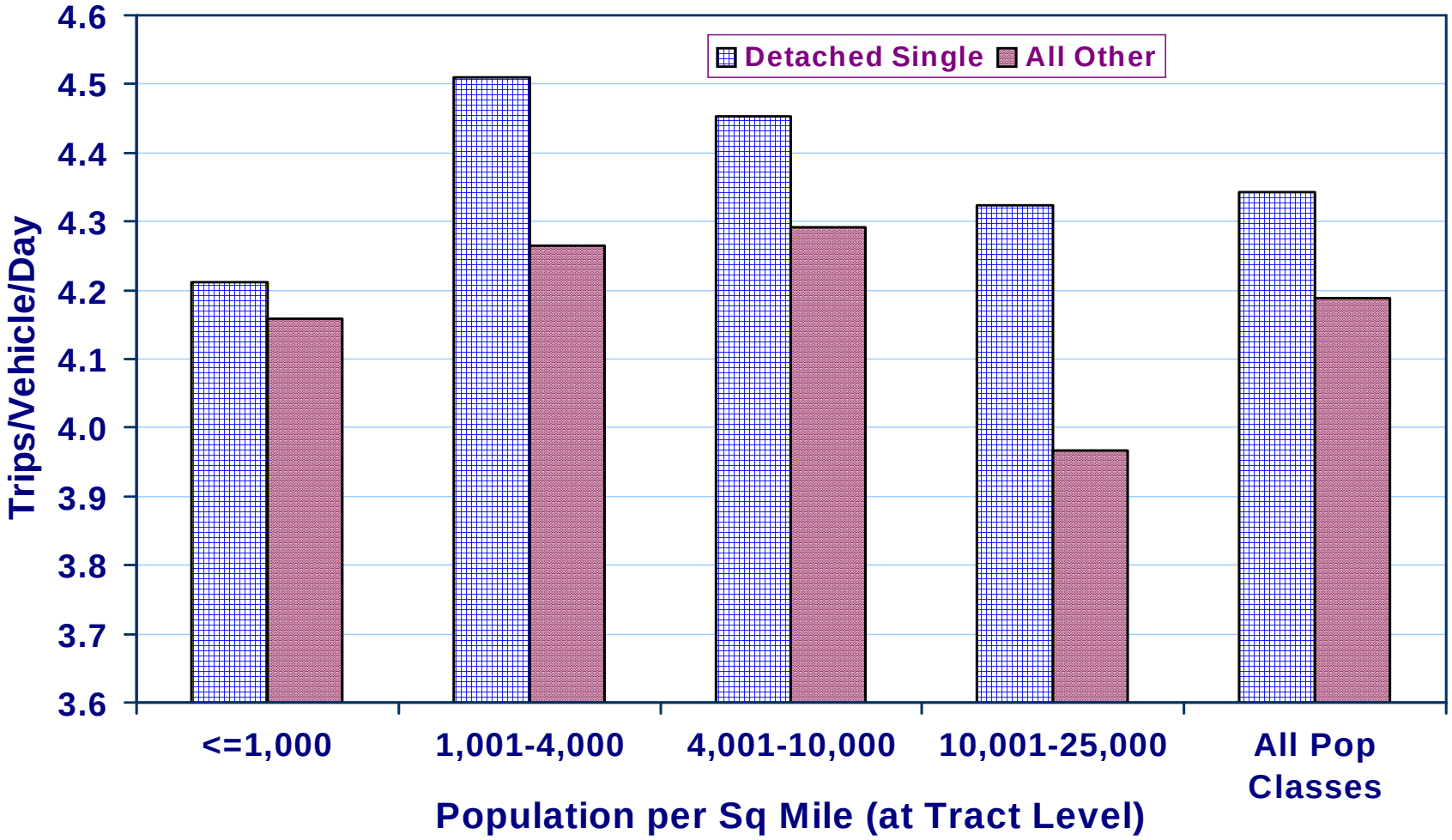
<u>Derivative questions relating to PHEV design, benefits:</u>

How many of the day's starts are "cold"?

How many of the trips could be in EV mode?

What is top speed of short trips?

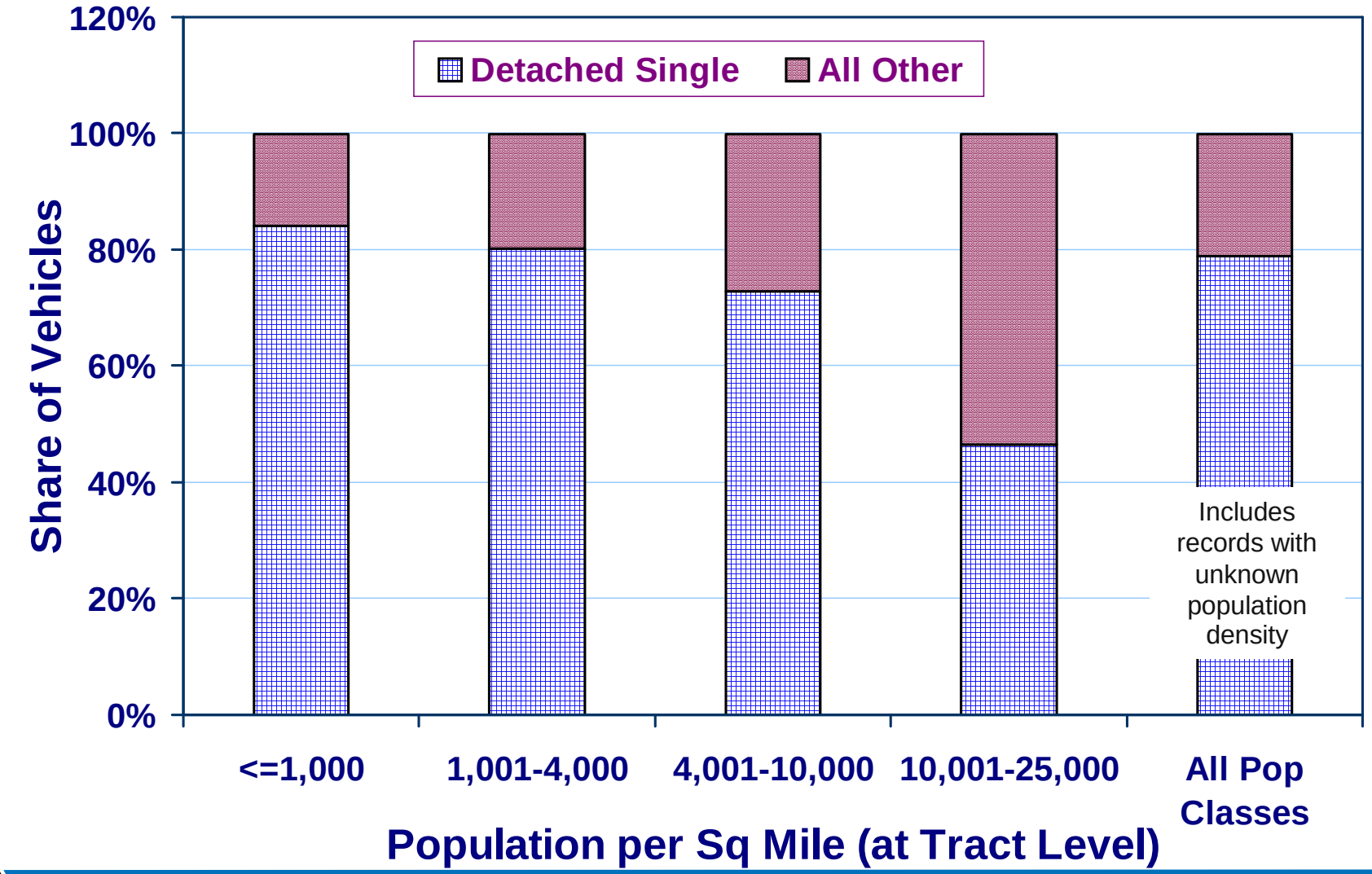
Garages & PHEVs: Detached Single Home Dwellers Make More Trips per Vehicle



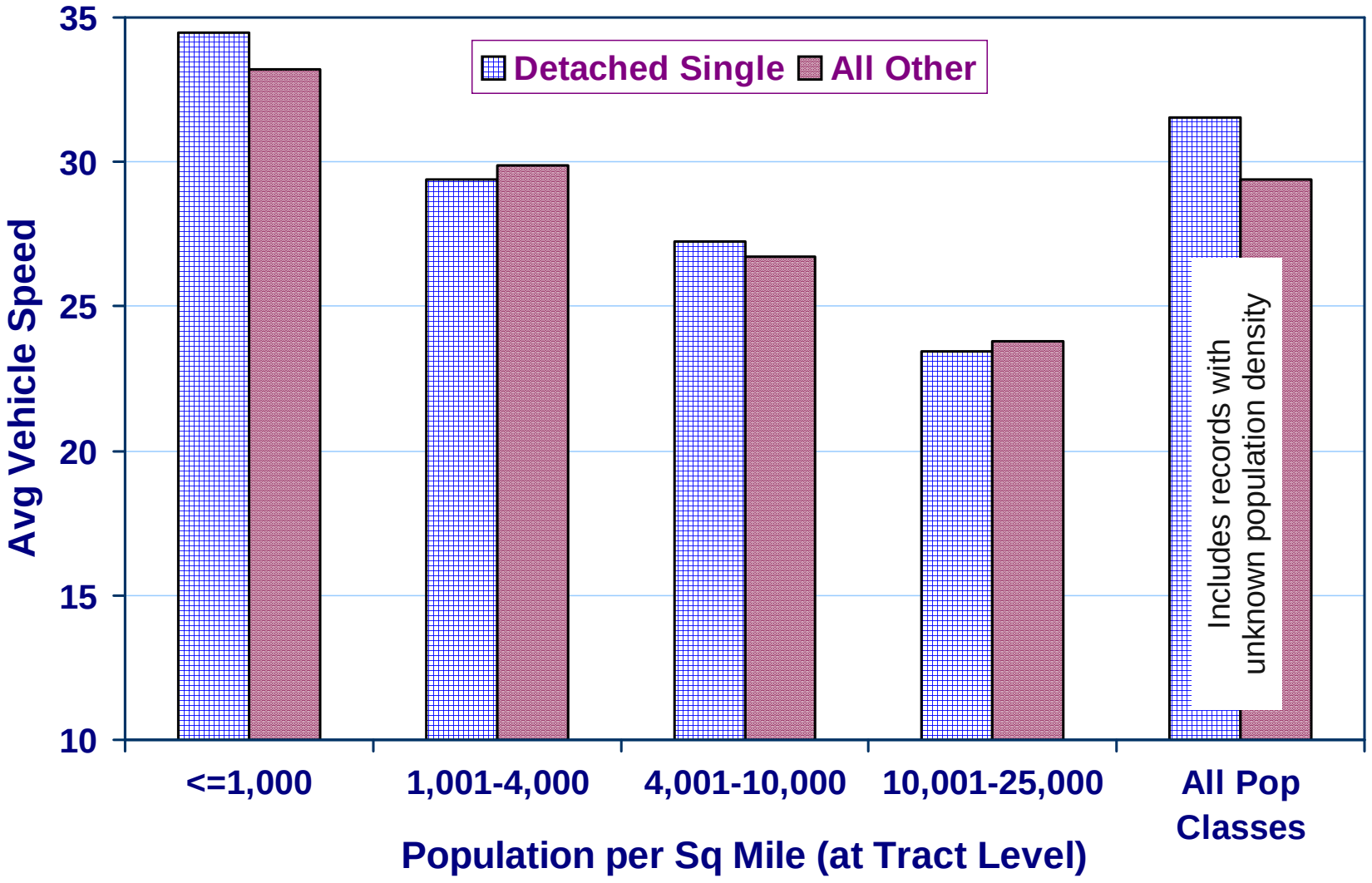
Source: 2001 National Household Transportation Survey

Note the conflicting starts per day implications vs. the prior slide.

The Share of Vehicles Affiliated with Detached Single Homes Drops At High Population Density

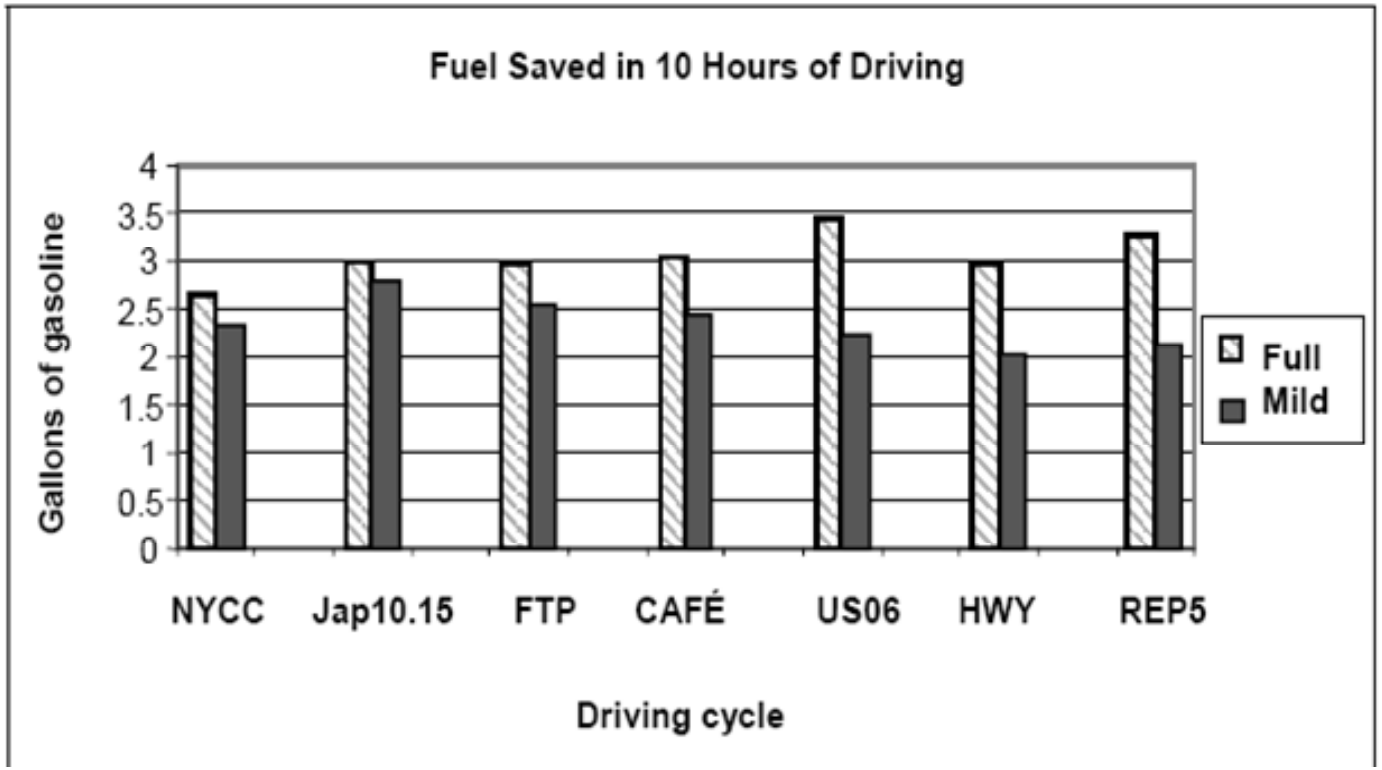


Vehicle Speed Drops As Population Density Increases. However …..



Think Differently About HEV/PHEV Fuel Advantage: Hrs/Driving are Key, Not the Miles

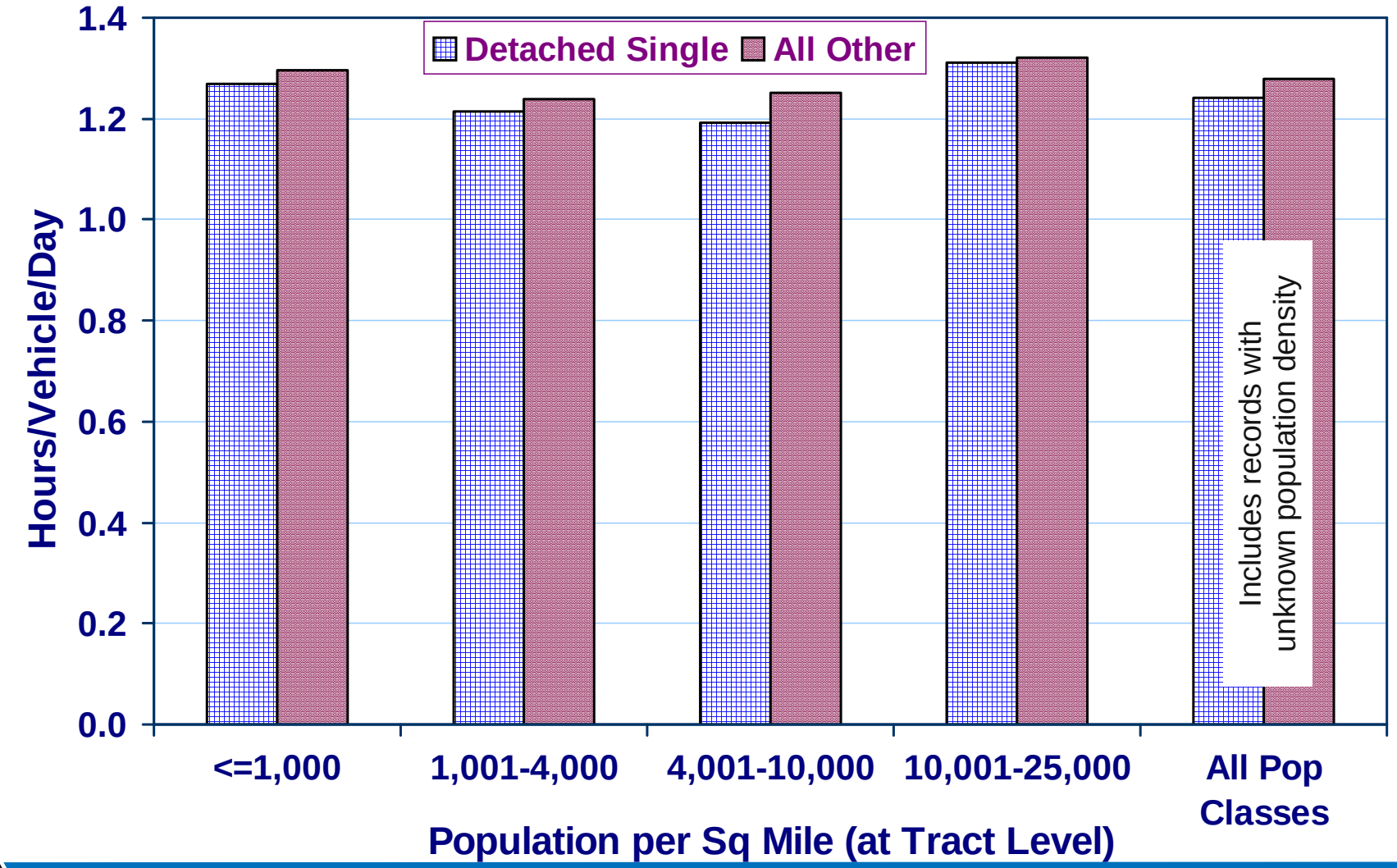
Note: Observation from U.S. NPTS and International studies: Hours per day are relatively constant across drivers in the U.S. and on average across nations



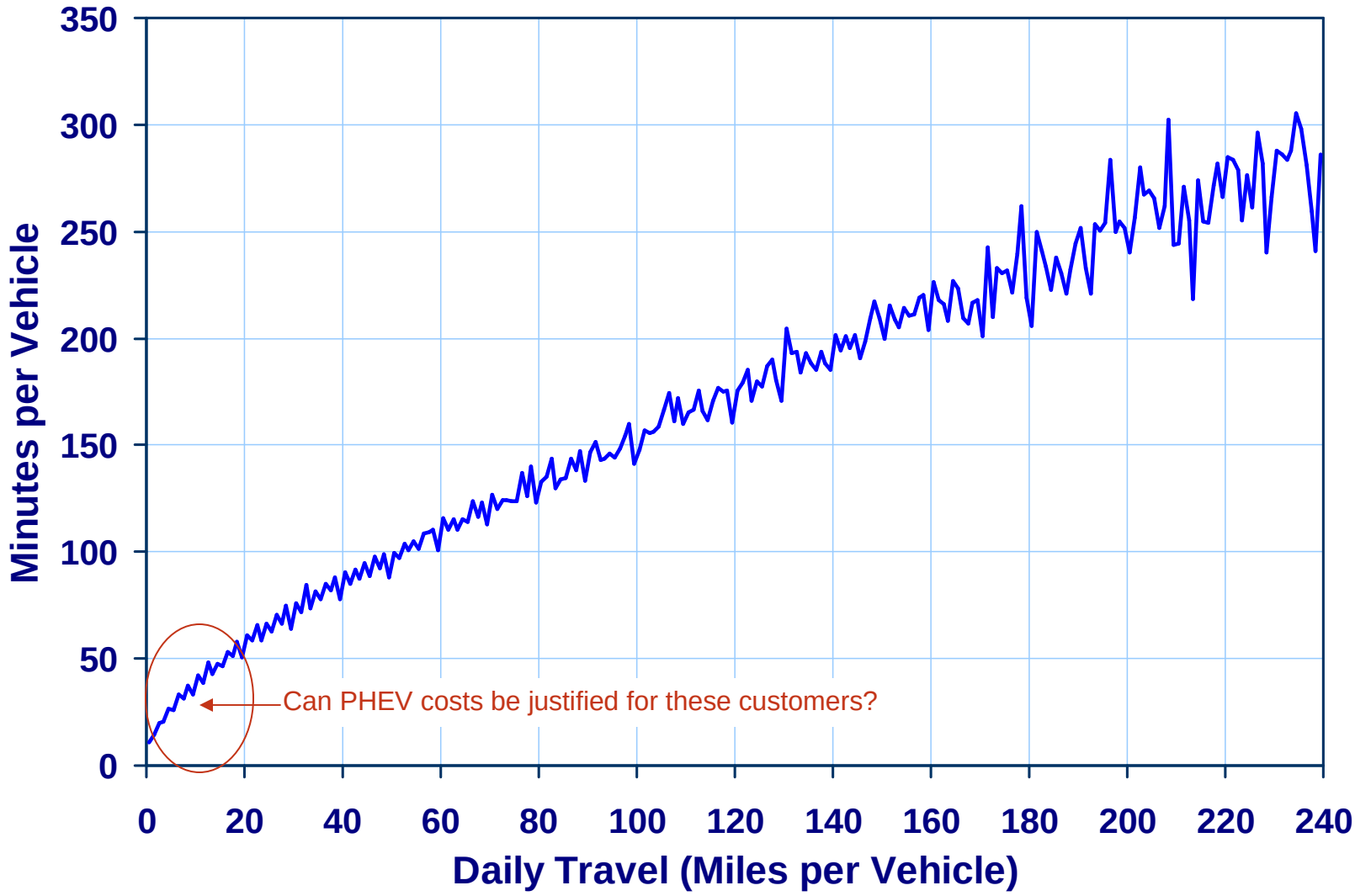
Predicted Hourly Fuel Savings by Switching from a Conventional Vehicle to Hybrid, by Driving Cycle

From Argonne Hybrid Electric Vehicle Technology Assessment, 2001

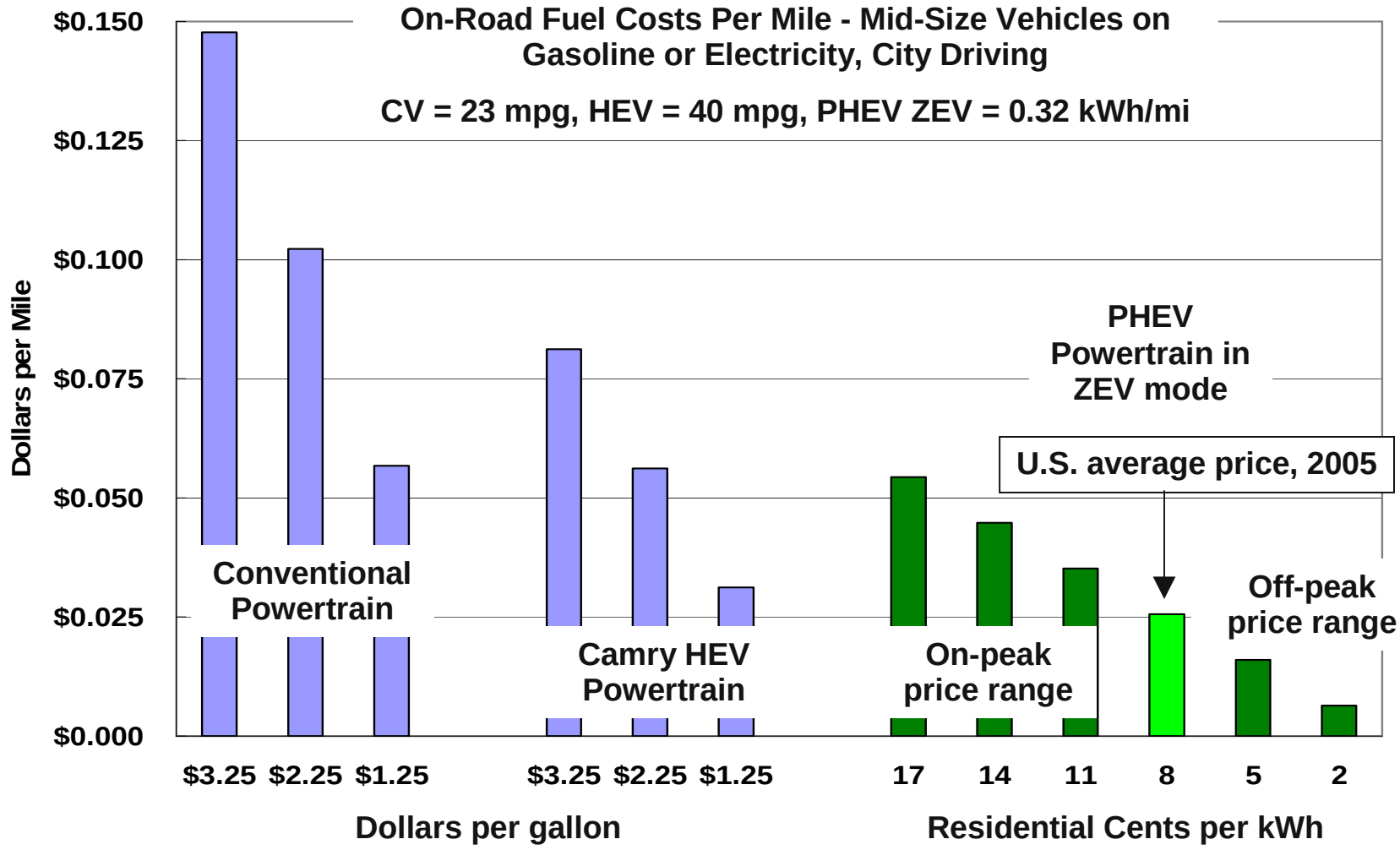
On Average, Hours per Vehicle Per Day are Relatively Constant Across Population Densities



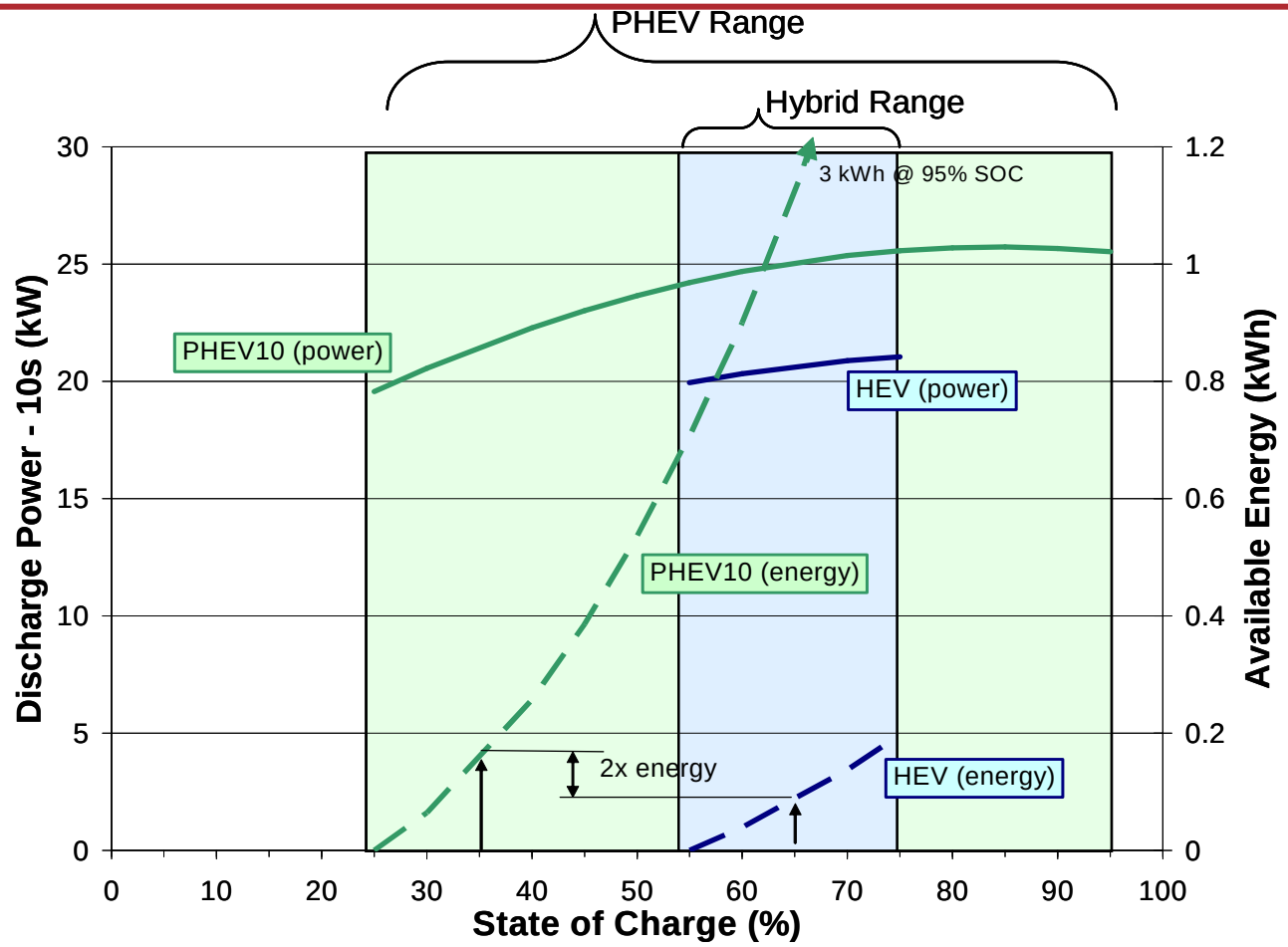
> = 22 Miles/Day/Vehicle, the Time in the Vehicle is an Hour and Above



U.S. Average Electric Rates Imply Considerable Per Mile Savings for PHEV20 Electricity Use at Present Gasoline Prices



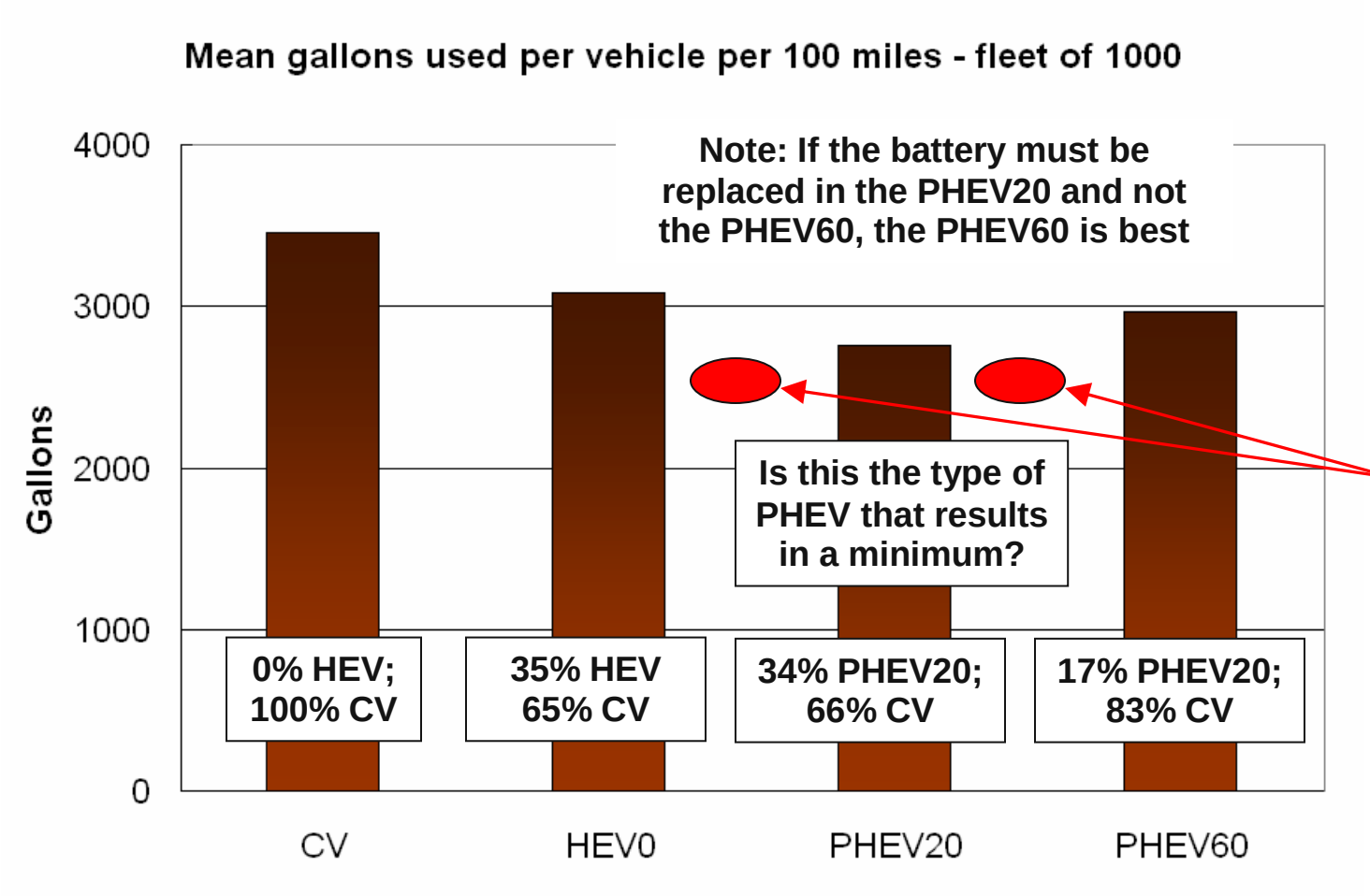
The Ability to Pull Electricity From a Battery to Move a Vehicle is Related to Power. Below Demanded Power, Less Power = More Time to Use a kWh. Battery Power Drops with DOD



Example: PHEV10 vs. HEV0, Li-ion pack simulation

Source: Plug-in HEVs: A Near-Term Option to Reduce Petroleum Consumption. T. Markel et al. NREL 05 Milestone Report, Jan., 19, 2006

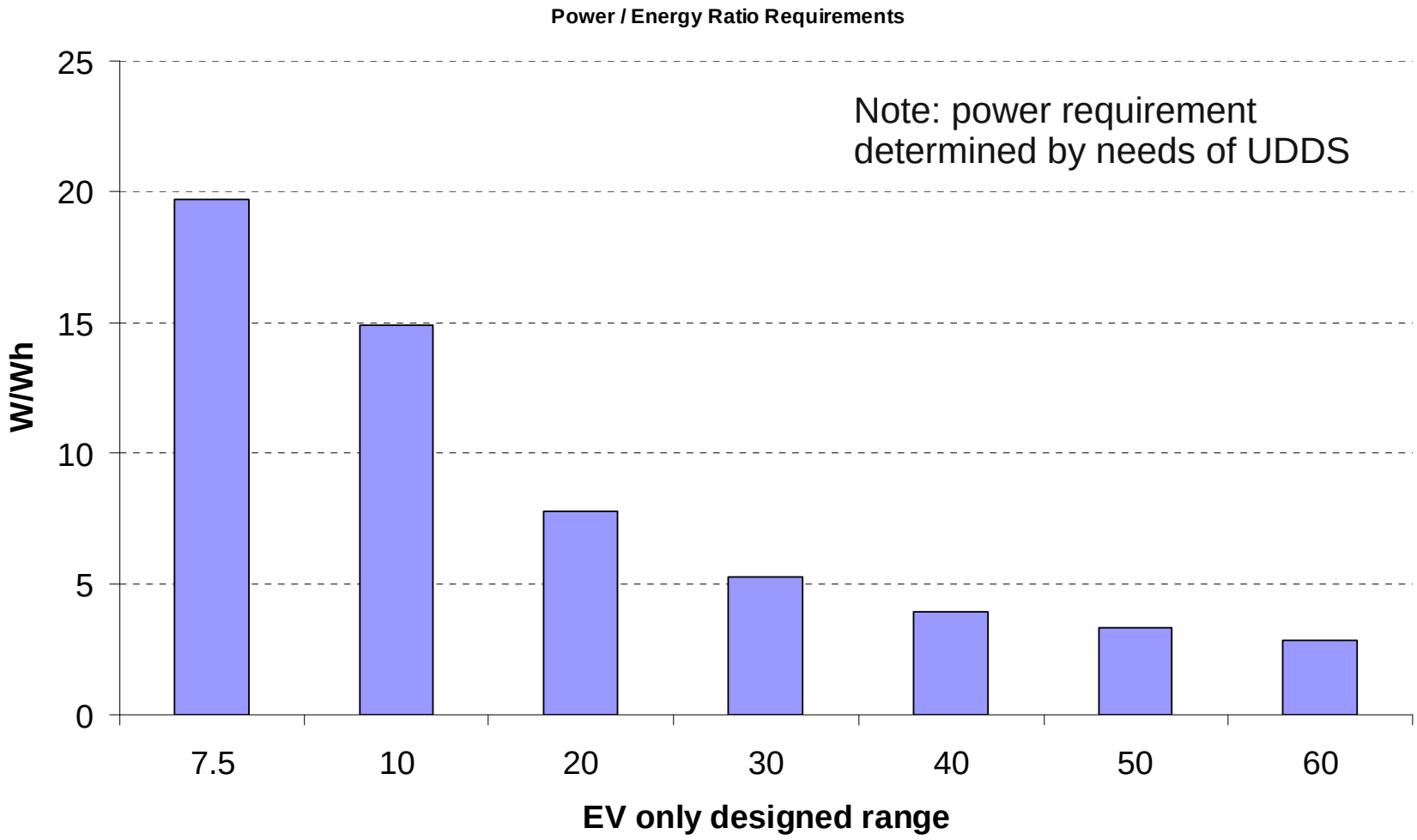
Considering EPRI HEV Type Market Share Estimates, Which PHEV Would Save Most Oil?



Mid-size car – HEV powertrain paired against the conventional (no other HEV competitor)

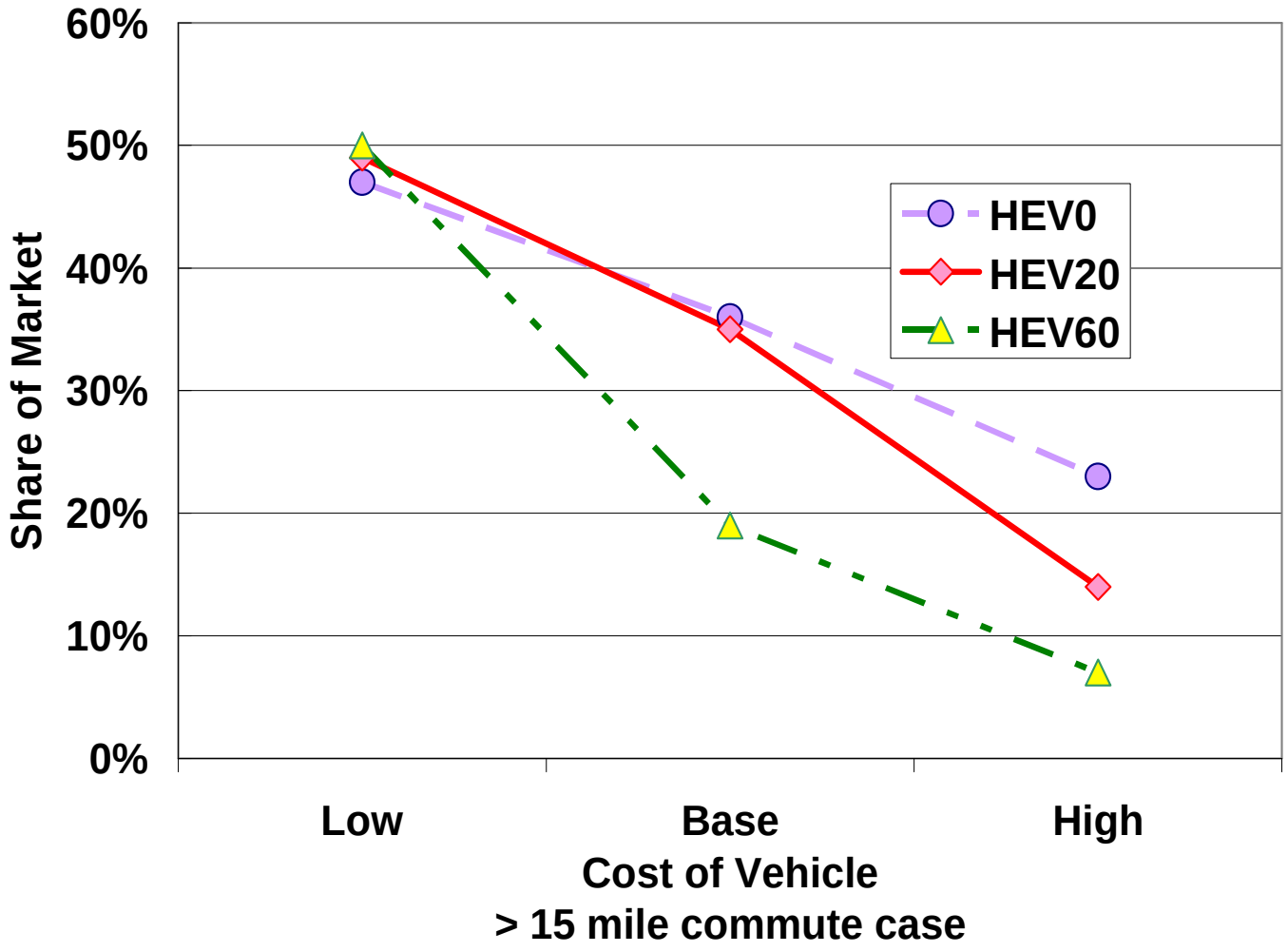
Source: EPRI 1000349, 2001

As the Range of PHEVs Rises, the Needed Battery Power to Energy Ratio Declines.
(This reduces $/kWh costs [not shown])



Source: PSAT simulations courtesy of A. Rousseau, Argonne

As Powertrain (Battery!) Costs Drop, EPRI Predicted Share of All HEVs Rises. For Long Commutes, Low Costs, PHEV60s Close the Gap



Summary on PHEV Range and Market Opportunities

- Average daily mileage is > 30 miles
- Vehicles driven from single family dwellings are driven more miles
- Detached single dwelling units are affiliated with a smaller portion of vehicles in the densest urban areas
- EPRI consumer preferences analysis indicated a subset of surveyed urban drivers with short commutes, with total driving averaging ~ 20 mi/day, had greatest interest in PHEV20s over HEVs, and consistently prefer PHEV20s over PHEV60s, regardless of price. Nevertheless, is this the right customer base to target?
- The EPRI survey also indicated that if less expensive batteries and PHEV powertrains emerge from R&D, a significant expansion of the market for longer range PHEVs could be realized among long range commuters.
- For long range commuters, in the EPRI low powertrain cost case (battery R&D success), PHEV60s were as likely to be chosen as PHEV20s.